Engineering Note
for
E906 Detector Assembly

PROJECT: E906

TITLE: Station 4Y Hodoscope Assembly

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ABSTRACT: This document describes an aluminum framework designed to secure an array of scintillators/photomultipliers in E906. Once assembled, this framework will also be used to hang the tubes in place in the E906 beamline. This scope of this document is limited to the detector assembly. The means of permanently hanging this detector must be addressed in separate engineering note.

DESIGN:
The scintillator bodies, light guides, and phototubes for station 4Y hodoscopes are provided by Abilene Christian University. Each body is coupled to two light guides and photomultiplier tubes to produce a Scintillator Assembly as shown in Figure 1.

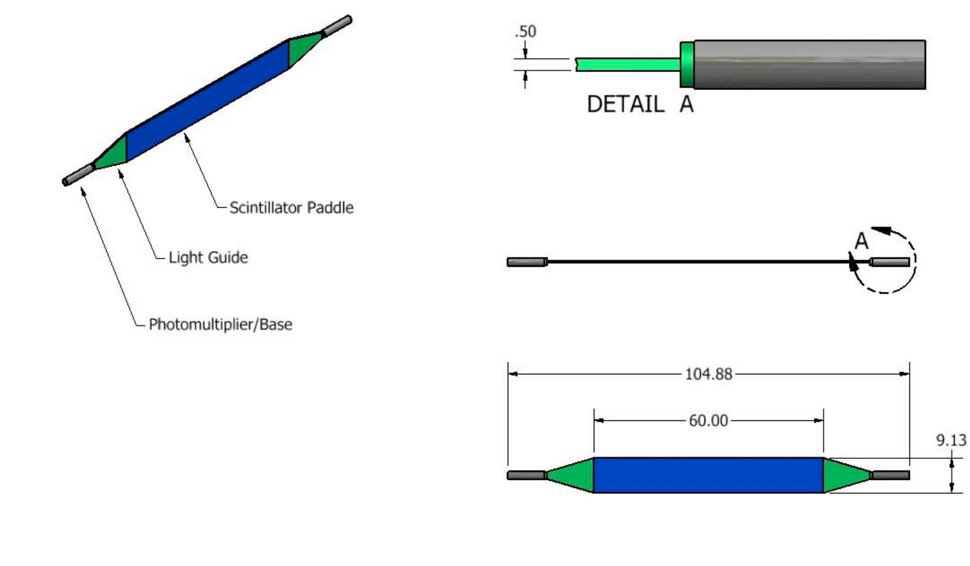

Figure 1: Station 4Y Scintillator Assembly
Approximate Weight = 15 lbs.

For each Station 4Y hodoscope array, 16 of these assemblies will be arranged with a slight overlap to form an array approximately 60" x 144". When placed into the beamline the scintillator assemblies will be oriented horizontally. They will be held in place by a framework consisting of aluminum extrusions and fastening hardware. The extrusions are produced by 8020, Incorporated and the proposed assembly for the E906 beamline is shown in Figure 2.

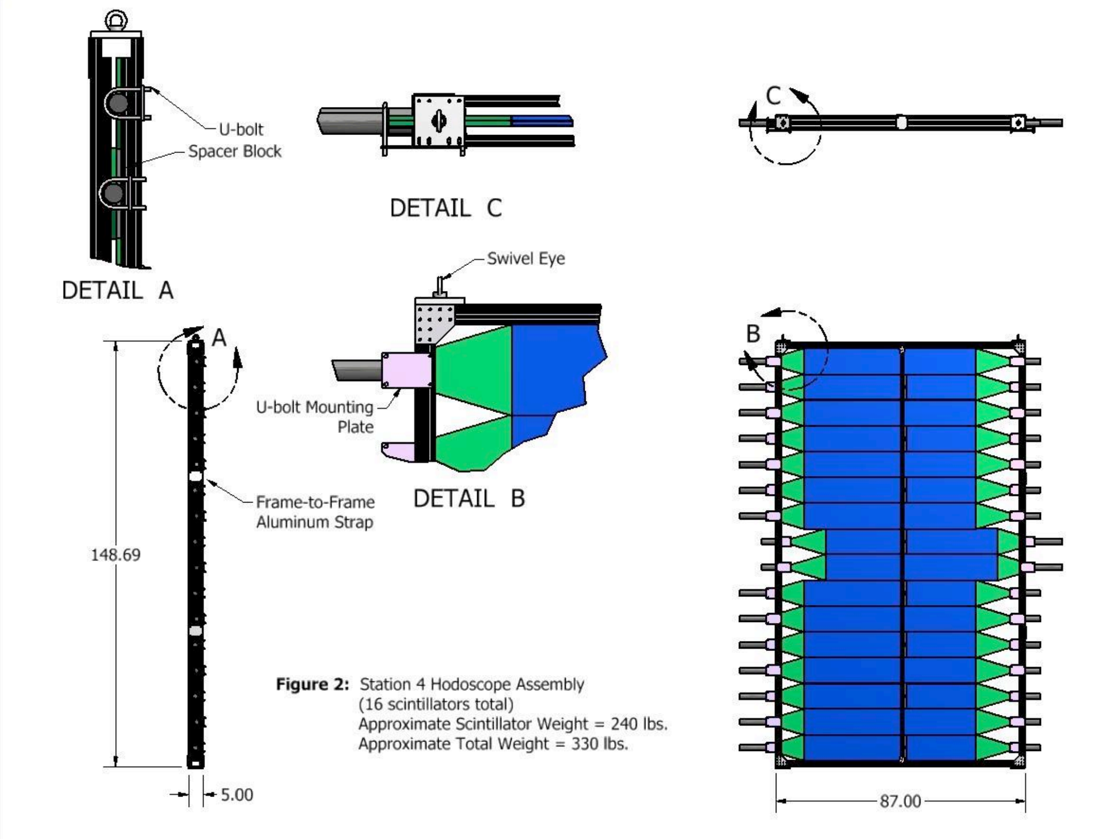

Figure 2: Station 4 Hodoscope Assembly
(16 scintillators total)
Approximate Scintillator Weight = 240 lbs.
Approximate Total Weight = 330 lbs.

The perimeter of the framework is constructed from extrusions with a 1" x 2" cross section, oriented such that the 2" width is parallel to the plane of the scintillators in order to minimize the thickness of the assembly. Within this perimeter is an additional 1" x 2" extrusion located near the midpoint of the scintillator bodies. This latter extrusion is used to mount spacer blocks in order to maintain proper separation between the scintillators. The scintillator assemblies will be secured to the framework by clamping the light guides in place with a u-bolt and mounting plate on each end. Table 1 lists the mechanical properties of the extrusion profiles relevant to this report:

Part No.	Cross Section	Area (in^2)	Material	lbs/foot	Ix (in^4)	Iy (in^4)
1020	1" x 2"	0.7914	6105-T5*	0.9212	0.3078	0.0833

- UTS = 38ksi minimum, Yield = 35ksi minimum, Emod = 10.2e6 psi,
- Allowable Tensile Stress = 19.5ksi*

*(per Aluminum Design Manual Part IA, 1994).

Table 1 – Mechanical Properties of 8020 Extrusions in 4Y Hodoscope Assembly per 8020 Fractional Parts Catalog – 16th edition

The weight of the framework is approximately 90 pounds and when this is added to the weight of the scintillators the total assembly weight is approximately 330 pounds. During assembly, the frames and tubes will be laid out horizontally. After assembly the entire package shown in Figure 2 will be lifted and rotated to be installed vertically into the E906 beamline.

ANALYSIS:
The hodoscope array will be built horizontally and then lifted/rotated and installed vertically in the E906 beamline with the tubes oriented horizontally. The assembly must be strong enough to withstand the rotation from horizontal to vertical and to hang vertically for the duration of the experiment. Each of these cases is treated separately as follows:

Lifting/Rotating:
When the array assembly is horizontal it can be lifted at one edge and re-oriented to the vertical. If the assembly is supported along the top and bottom edges then the weight of the scintillators is essentially borne by two pairs of 1020 extrusions. The total thickness of the framework is 5 inches and the separation between the centers of these extrusions is 4 inches, with one extrusion located 2 inches above the mid plane and the other extrusion located 2 inches below the mid plane. By substituting the appropriate values from Table 1 into the Parallel Axis Theorem, the resulting moment of inertia of each extrusion can be calculated as follows:

Parallel Axis Theorem: $I_z = I_x + A*r^2$ **(1)**

Where: I_z is the moment of inertia about the parallel axis
I_x is the moment of inertia of the 1020 extrusion (Table 1)
A is the area of the 1020 extrusion (Table 1)
r is the distance to the parallel axis (2")

$I_z = 00833\text{in}^4 + (0.7914\text{in}^2)*(2\text{in})^2 = 3.2489\text{in}^4$

Since there are two extrusions along each edge the total value for I is twice the value calculated above, or 6.4978in^4.

If the framework is treated as beams supported on both ends subject to uniform loading then the stress and deflection can be calculated using standard formulas:

Stress at center of constant cross section: $s = \frac{-Wl}{8Z}$ **(2)**

Maximum deflection at center: $y = \frac{5}{384}\frac{Wl^3}{EI}$ **(3)**

Where: W is the weight supported by the beams (165lb)
l is the length (148 inches)
I is the combined moment of inertia, 6.4798in^4.
Z is the section modulus
E is the modulus of elasticity

Substituting the values into equation (2) yields:

$$s = -\frac{1}{8}\left[\frac{165lb \times 148in}{\left(6.4978in^4 \big/ 2in\right)}\right] = -939.5lb/in^2$$

Likewise, substituting the values into equation (3) yields:

$$y = \frac{5}{384}\frac{165lb \times (148in)^3}{10.2e6\,psi \times 6.4978in^4} = 0.105in$$

> The Allowable Bending Stress for a 2020 extrusion with a length of 148" (per Aluminum Design Manual Part IA, 1994) is 20,360psi. The maximum stress of 939.5psi, when compared to this value for Allowable Bending Stress, provides a safety factor of 20360/939.5 = 21.7. The maximum deflection of 0.105" occurs at the start of the rotation and will fall to zero as the array is made vertical.

Ultimately the weight of the entire array/framework assembly is held by two swivel-action eyebolts with 1/2-13 threads. These are bolted to steel plates which are in turn fastened to the framework using a total of eight ¼-20 screws per plate (See Figure 2, Detail B, C). At the start of rotation all of these fasteners will experience a stress due to shear and this stress will vanish as the array is rotated. The maximum shear applied to the eyebolts and screws is calculated as follows:

> Each swivel-eyebolt supports approximately 165-lbs. The area of a ½-13 bolt, based on a minor diameter of 0.4041-in^2, is 0.128-in^2 and the resulting shear stress in each eyebolt is 165/0.128 = 1289.06psi. We have identified swivel eyebolts made from forged alloy steel type AISA-SAE 4140 (American Drill Bushing, part number 33515) with a minimum tensile strength of 180ksi, which is well in excess of the actual values stated above. These bolts are certified for a work load limit of work load limit of 2500-lbs with a pivot range of 180 degrees and a swivel range of 360 degrees and are suitable for this application.
>
> Also, each ¼-20 screw experiences a shear force of roughly 20.6-lbs. With a minor diameter of 0.1887 and an area of 0.0280in^2, the resulting shear stress in each ¼-20 screw is 736.6psi. Grade 5 screws with yield strength of 92ksi (per SAE J429) are readily available. Assuming shear strength is 60% of yield strength results in shear strength of 55ksi which is far in excess of the expected actual value.

Placement in E906 Beamline:
Once the detector assembly is vertical the weight of the tubes is borne by two 1020 extrusion that run vertically along the edges of the framework. With an area of 0.7914in^2

(Table 1) and a weight per column of 165lbs the tensile stress on each vertical extrusion is 165/0.7914 = 208.5psi and is not a cause for concern when compared to the allowable tensile stress of 19.5ksi.

The steel plates shown in Figure 3 (Detail A) will also experience stress and deflection as a result of the same 165lb load. Assume the plate is made from 18-8 stainless steel with yield strength of 40ksi. If the plate is 5" long and 0.5" thick then the moment of inertia is 0.052-in^4 and the section modulus is 0.208-in^3. Under these conditions this plate will experience a stress of 495psi, which is well below the yield strength, and the deflection will be negligible.

Finally, in the beam line the weight of the entire array/framework assembly is held by the swivel-eyebolts and ¼-20 screws in tension (See Figure 2, Detail A). The tension in these components is calculated as follows:

> Each swivel-eyebolt experiences a tensile force of approximately 165-lbs which is well below the work load limit of 2500-lbs for the swivel eyebolts identified above.
>
> Likewise, each ¼-20 screw experiences a tensile force of roughly 20.6-lbs. With a tensile stress area of 0.0318in^2, the resulting tensile stress in each ¼-20 screw is 647.8psi, which is acceptable for Grade 5 screws per SAE J429.